

IN-71-TM

## INVESTIGATION OF SONIC BOOM FOR THE SPACE

5042

SHUTTLE: HIGH CROSS-RANGE ORBITER

p. 12

By

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INTRODUCTION

Recent studies of a proposed low cross-range straight-wing space shuttle orbiter have shown that the sonic boom created during reentry may be objectionable, particularly at low supersonic Mach number (ref. 1). Because of this, additional tests have been conducted to determine the sonic-boom overpressure for a blended wing-body shape proposed for use as a high cross-range shuttle orbiter. Two mission profiles, in which a constant angle of attack was held during the supersonic portion of the flight, were studied. In one case the angle of attack was 60 degrees; in the other 25 degrees. The sonic-boom pressure signatures were measured in a wind tunnel and used to estimate overpressures for both missions. A technique for alleviating the boom is indicated.

## NOMENCLATURE\*

$F(y)$	effective area function (see ref. 2)
$G$	deceleration
$h$	flight altitude
$M$	Mach number
$p$	reference pressure
$y$	distance along axis of vehicle
$y_o$	value of $y$ for which $\int F(y)dy$ is a maximum
$\alpha$	angle of attack
$\Delta p$	sonic boom overpressure
$\gamma$	flight path angle, negative below the local horizontal

\*All units given in mks and English systems unless otherwise noted.

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Ames Research Center) 12 p

## METHOD

Because the Whitham theory (ref. 2) does not provide for the calculation of an F-function for a vehicle with detached shock waves it was necessary to employ a method which utilizes an F-function determined from wind tunnel tests (ref. 3). Following this method, the sonic-boom pressure signature is measured at two distances,  $h_1$  and  $h_2$ , from the model in a wind tunnel. The signature obtained at  $h_1$  is then used to calculate an F-function. The F-function so determined can then be used to predict the pressure signature at  $h_2$ . If the agreement between the predicted and the measured signature at  $h_2$  is acceptable, it is then possible to use either signature to estimate, with some confidence, the level of overpressure on the ground for flight at a given altitude.

Since the method of reference 3 is applicable to level, unaccelerated flight in a uniform atmosphere it is necessary to correct the level of overpressure for a nonuniform atmosphere (ref. 4), deceleration (ref. 5) and flight-path angle. The procedure used in correcting for flight-path angle has been described in reference 1 and will not be repeated here.

## TEST CONDITIONS AND APPARATUS

A .254 meter (10 inch) model of a blended wing-body shape (fig. 1) proposed for use as a high cross-range orbiter by the North American Rockwell Corporation has been tested at Mach numbers of 1.68 and 2.17 in the Ames 2.7 x 2.1 meter (9- x 7-ft.) wind tunnel and at a Mach number of 2.7 in the Ames 2.4 x 2.1 meter (8- x 7-ft.) wind tunnel. The total pressure used was 508 mm-hg (20 in-hg) in both tunnels. The model was tested at angles of attack of 25 and 60 degrees in both tunnels. The two angles of attack were obtained by attaching the model to its sting support in either of two appropriately inclined holes on the top of the fuselage (see fig. 1).

The model was mounted on a linear actuator (fig. 2) which provided a longitudinal travel of .736 m (29 in). Pressures in the flow field were measured using a 2 deg., conical, static-pressure probe mounted on the wall center line as shown in fig. 2. The probe shown in the figure near the top of the wall was outside the model flow field and was used to transmit the free-stream static pressure to a transducer.

## RESULTS AND DISCUSSION

An experimental investigation was conducted to determine the sonic-boom characteristics of a blended wing-body orbiter for the trajectories shown in figs. 3 and 4. The large shock strength associated with the detached bow wave (fig. 5) made it necessary to establish the validity of the near-field extrapolation technique (ref. 3). This was accomplished, as described in the METHOD section, for the angle of attack flown in both trajectories. The results are shown in figures 6 and 7. The near field extrapolation technique was verified only at a Mach number of 2.7 since at this Mach number the bow shock strength is largest and the technique is subject to the greatest inaccuracies. The pressure signatures obtained at a Mach number of 1.68 and 2.17 are shown in figures 8 and 9.

The signatures shown in figures 6 through 9 were used as described in the METHOD section to predict the sonic-boom characteristics for flight conditions. A reflection factor of 1.8 was assumed. As can be seen in figure 10, the level of overpressure is large enough to be potentially objectionable for communities under the flight path for the 60-degree angle-of-attack trajectory. The level of overpressure for the 25 degree trajectory shown in fig. 10 is below 50 N/m<sup>2</sup> (1 psf) over the Mach number range shown. Overpressure of this magnitude probably would not present a serious sonic-boom problem for communities under the flight path.

In order to separate the effects of trajectory from angle of attack, the sonic-boom characteristics for reentry at 25-degrees angle of attack were also assessed assuming flight along the 60-degree trajectory. As indicated by comparing the circles with the solid squares reentry along the same trajectory at the lower orbiter attitude ( $\alpha = 25^\circ$ ) results in a reduced overpressure at all Mach numbers. A comparison of the open squares with the solid squares gives the effect of trajectory for constant attitude. As can be seen the effect of trajectory is smaller than the effect of attitude for the trajectories of this study.

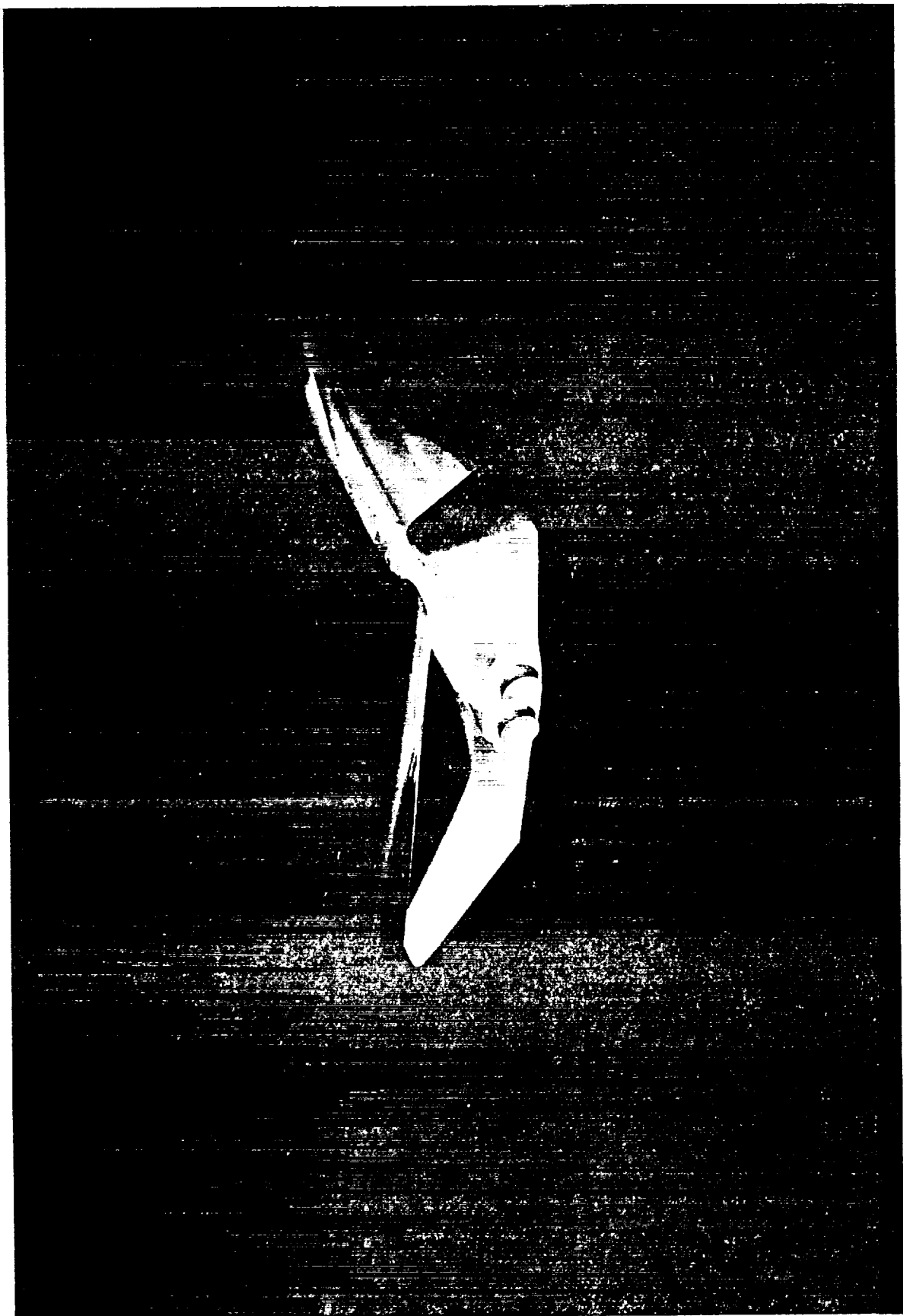
In addition to corrections for flight-path angle, nonuniform atmosphere, and deceleration, the effect of rate of change of flight-path angle on the data shown in fig. 10 was investigated and found to be negligible. The effects of bank angle and rate-of-change of heading angle were not investigated during this study. However, future effort should be devoted to a study of these effects since the sonic-boom characteristics of a high cross-range orbiter might be affected by these parameters.

No data were obtained at a Mach number of 1.2 during this investigation because of unsteady-flow conditions (and consequent questionable data) observed at this Mach number during the studies of ref. 1.

#### CONCLUDING REMARKS

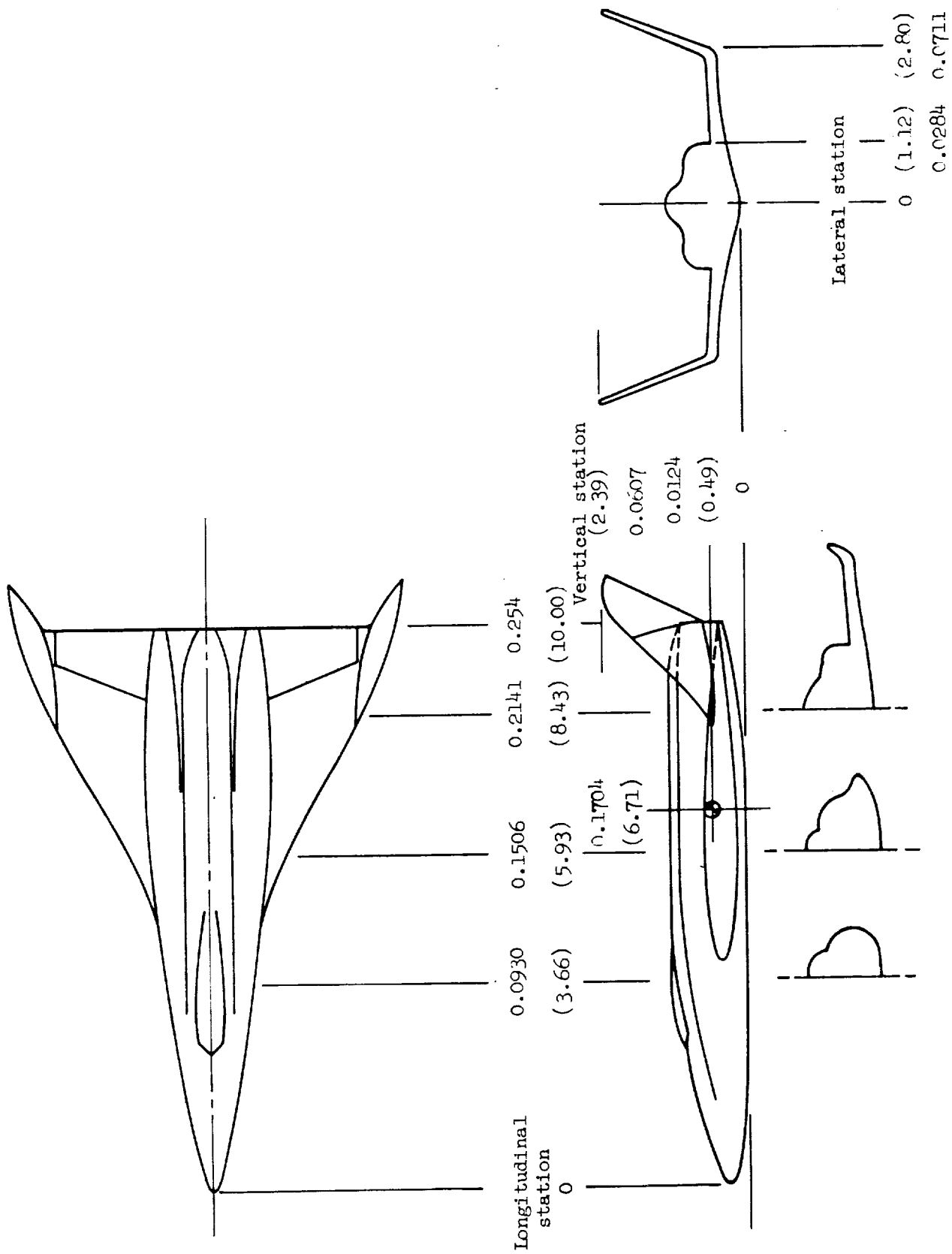
The sonic-boom characteristics of a blended wing-body, high cross-range orbiter have been studied at Mach numbers of 1.68, 2.17 and 2.7 for mission profiles flown at 25- and 60-degrees angle of attack. The data indicate that by careful selection of the mission profile and orbiter attitude it is possible to keep the bow-shock overpressure below  $48 \text{ N/m}^2$  (1 psf); a level which may be acceptable to communities under the flight path.

Further work is needed to define the effects of bank angle, rate-of-change of bank angle and rate-of-change of heading angle on the level of sonic-boom overpressure.



(a) Sting position for  $\alpha = 25^\circ$

Figure 1.- Blended wing-body model.



(b) Model dimensions, meters (inches)

Figure 1.- Continued.

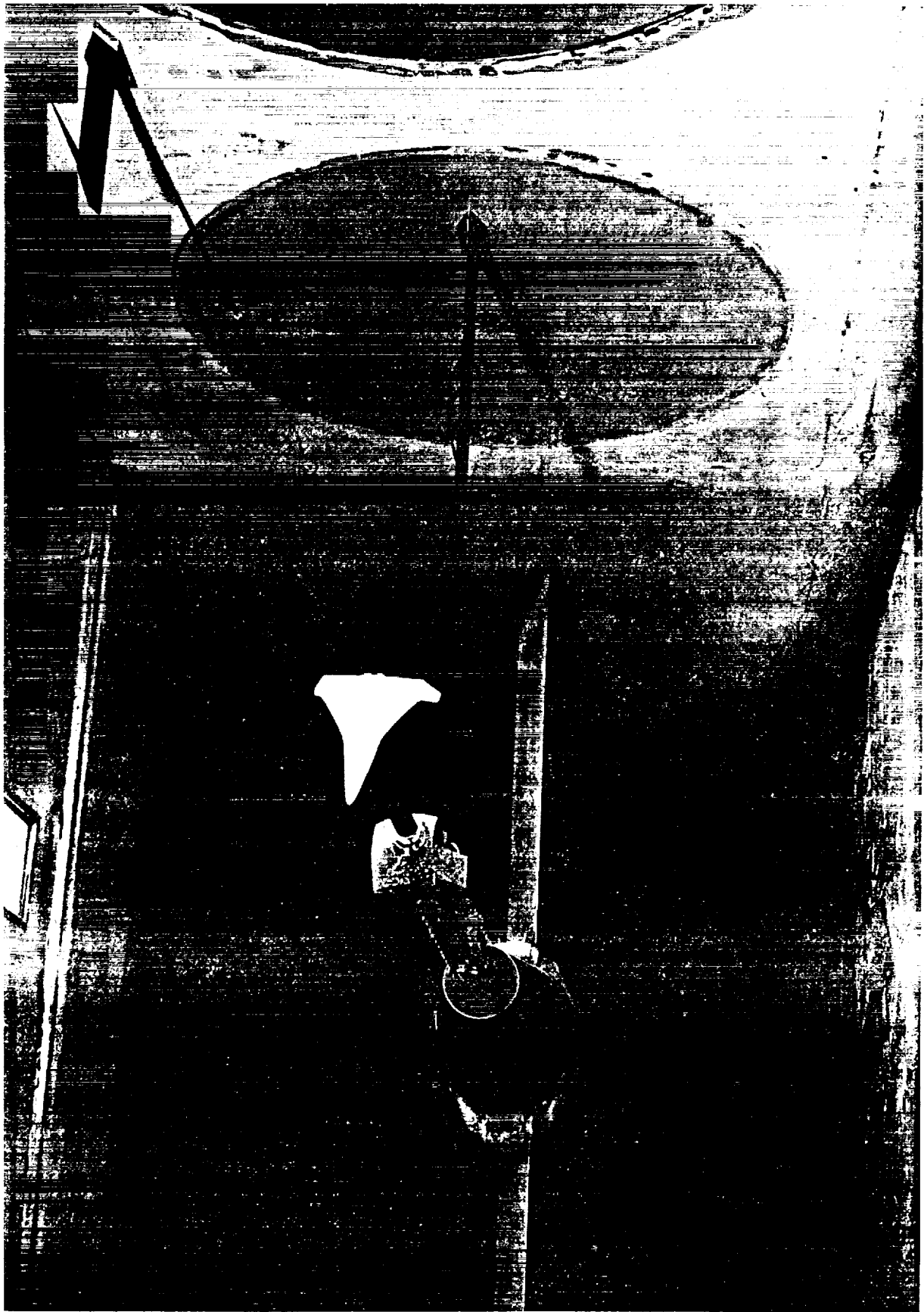


Figure 2.- Model mounted on linear actuator in 2.7 x 2.1 meter (9-by 7-Foot) Wind Tunnel.

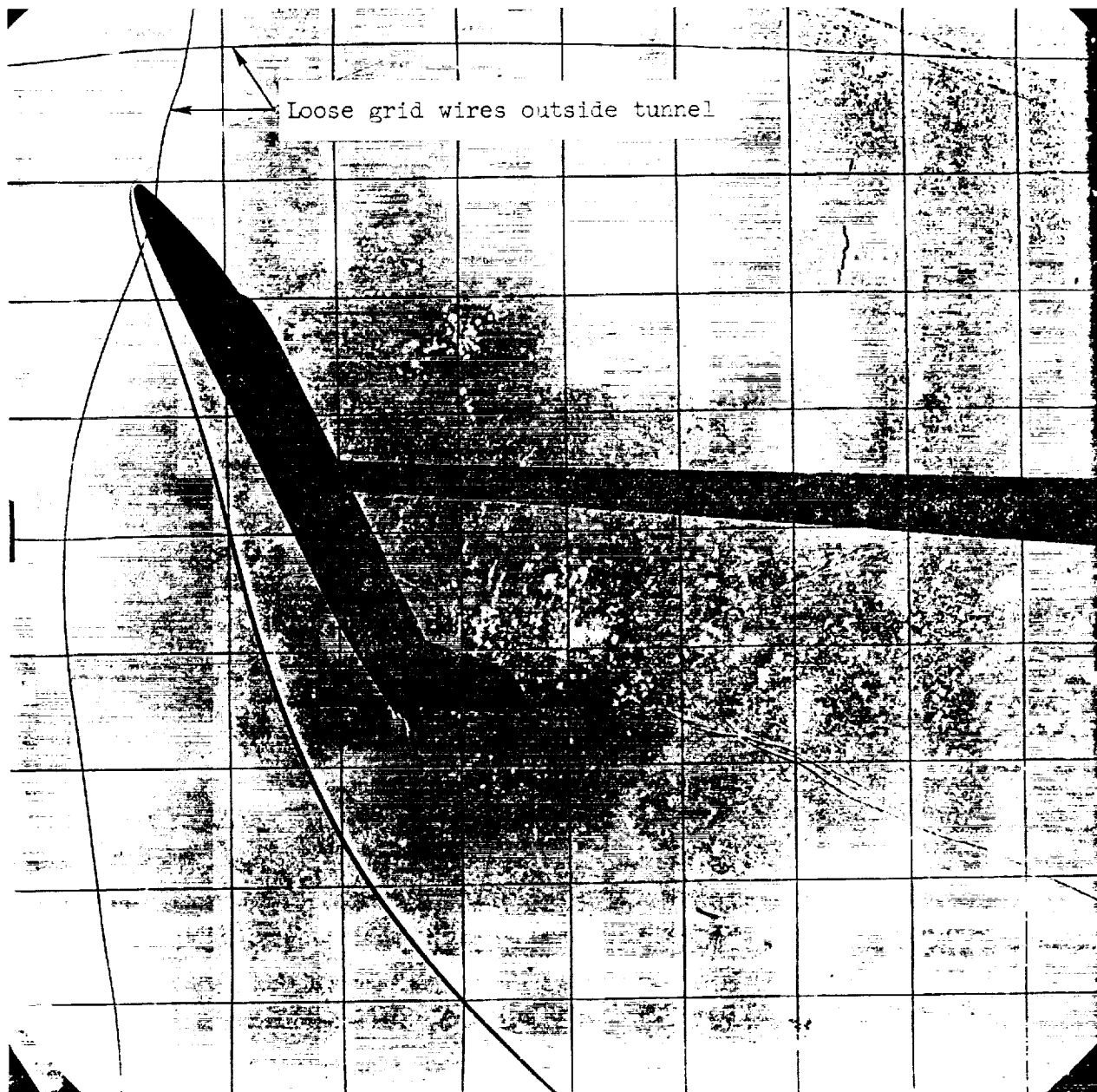


Figure 5.- Shadowgraph of Delta Wing Orbiter;  $M = 2.7$ ,  $\alpha = 60^\circ$ .

9-10

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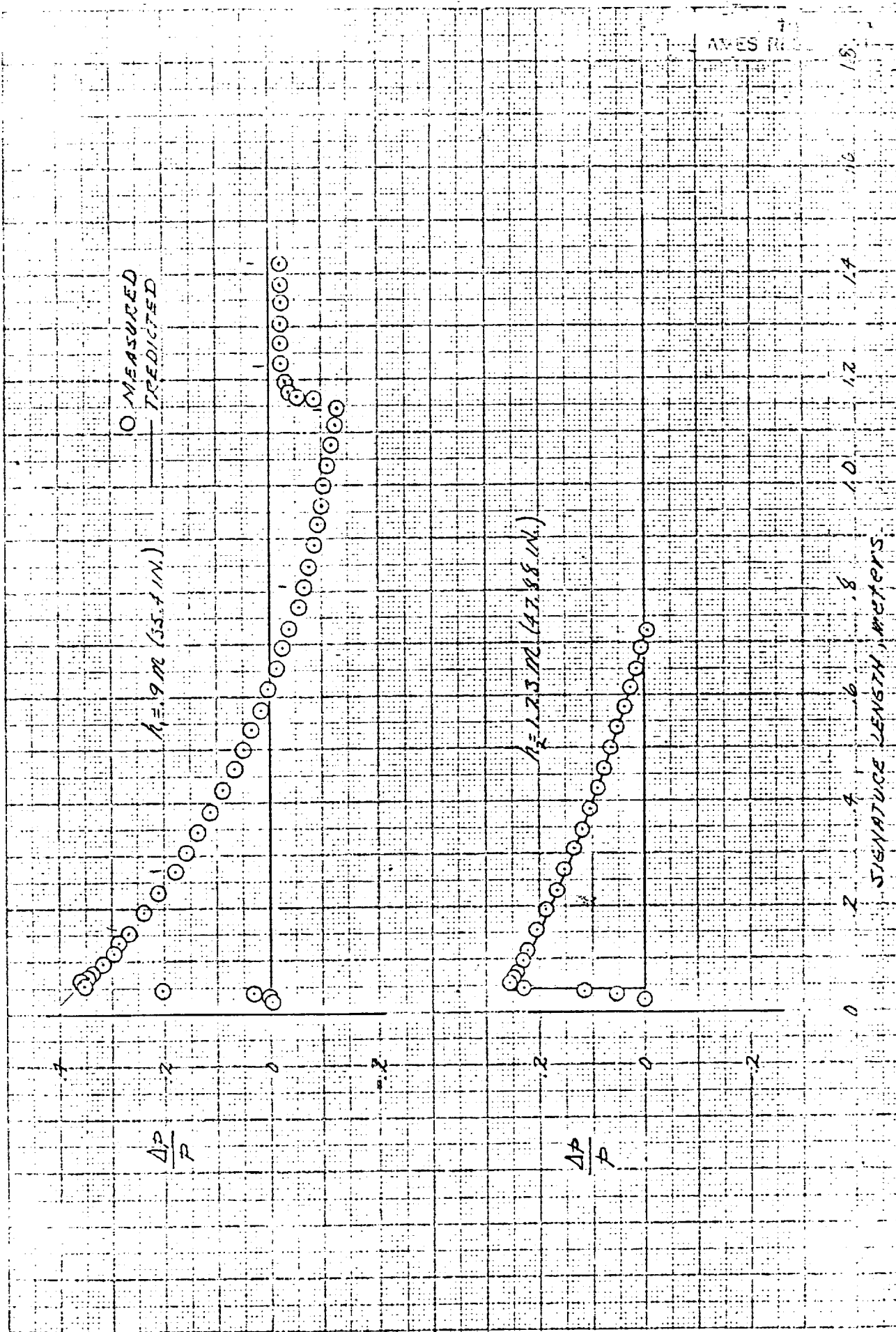


FIG. 6 COMPARISON OF MEASURED AND PREDICTED SIGNATURES,  $M = 3.7$ ,  $\alpha = 60^\circ$

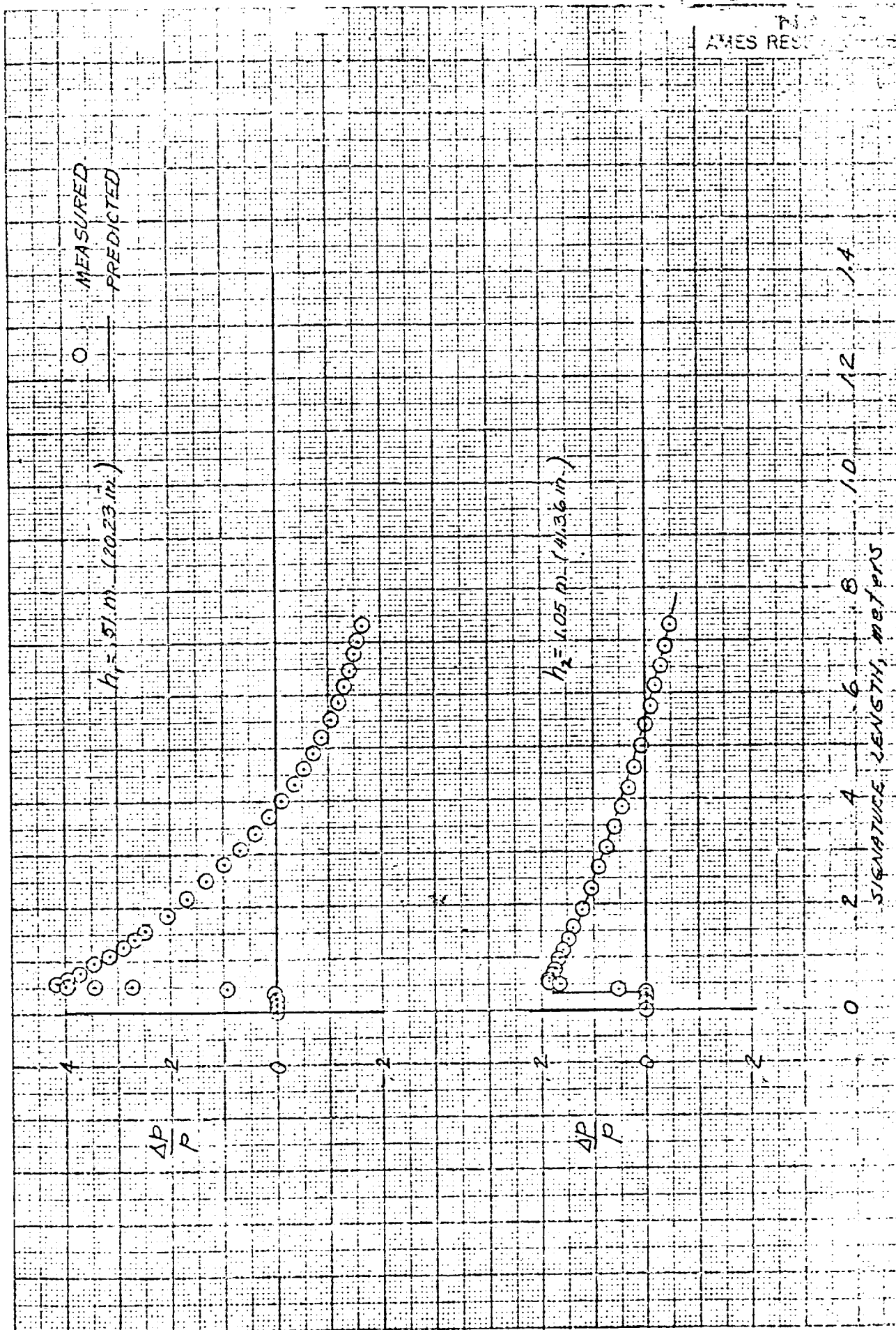


FIG. 7 COMPARISON OF MEASURED AND PREDICTED SIGNATURES,  $M=2.7$ ,  $\alpha=25^\circ$

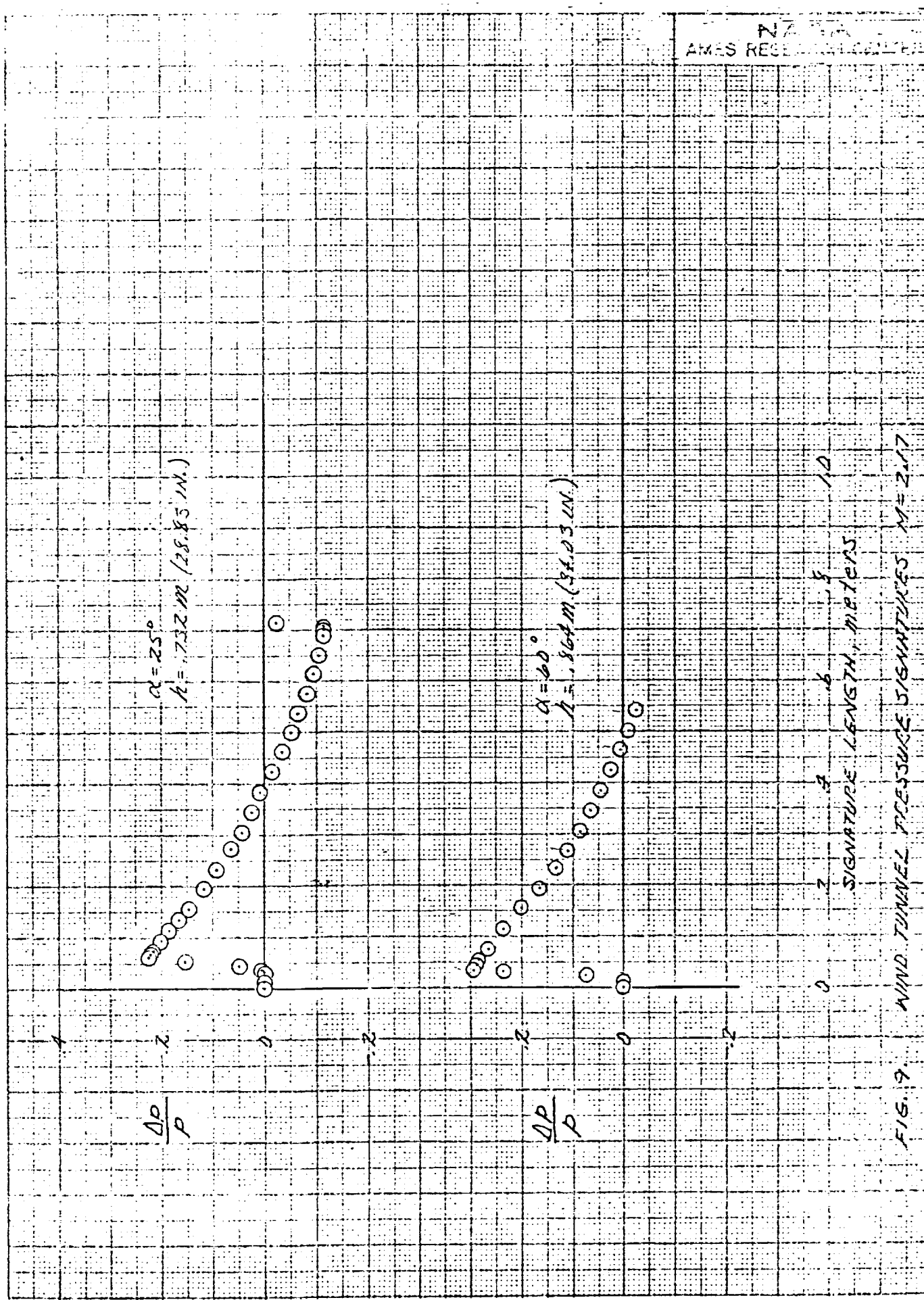


FIG. 9 WIND TUNNEL PRESSURE SIGNATURES  $M = 2.17$

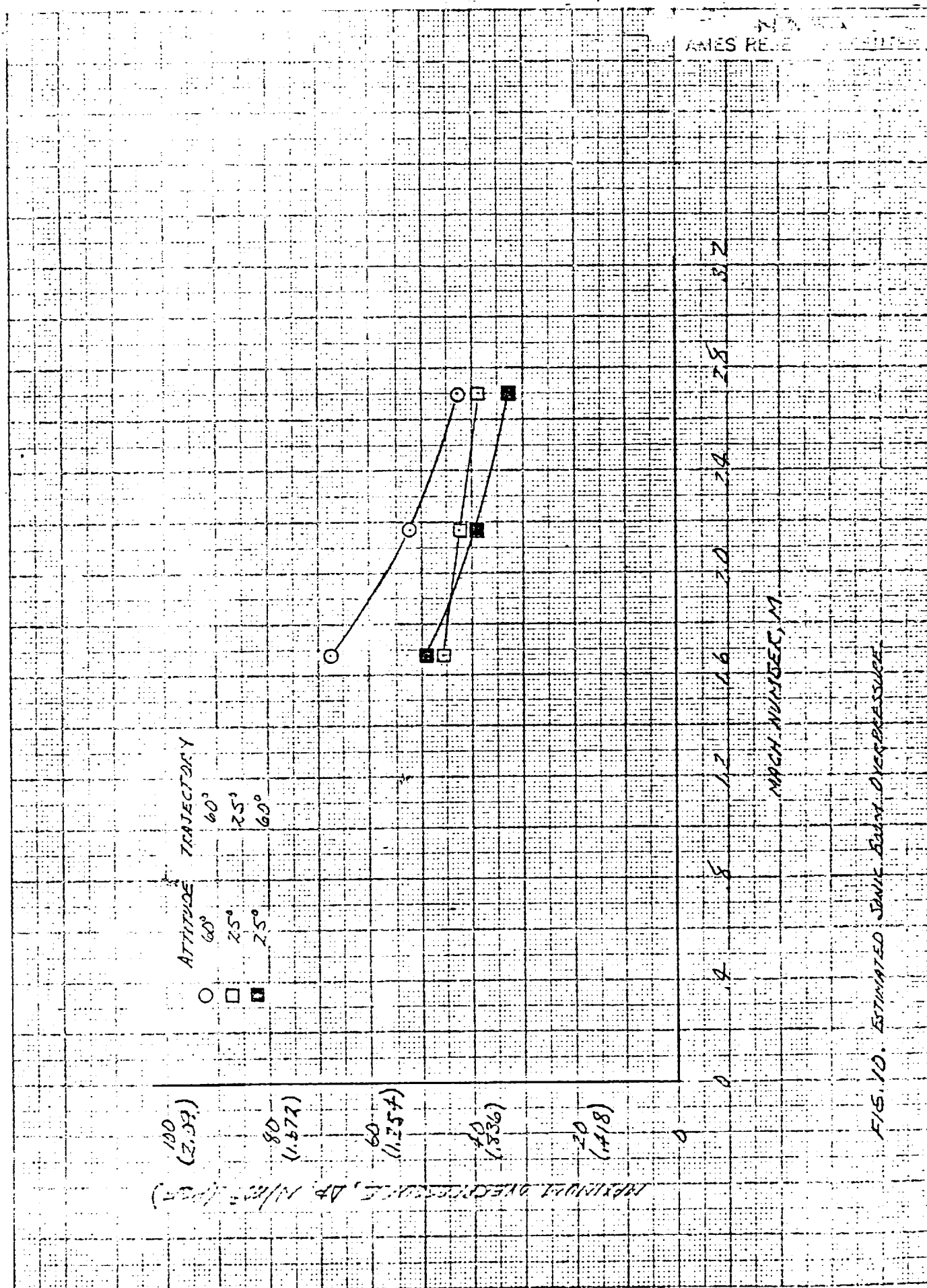


FIG. 10. ESTIMATED SONIC BOOM OVERPRESSURE